NMME Sub-seasonal Forecast System Exploratory Workshop

Land-Atmosphere Interactions

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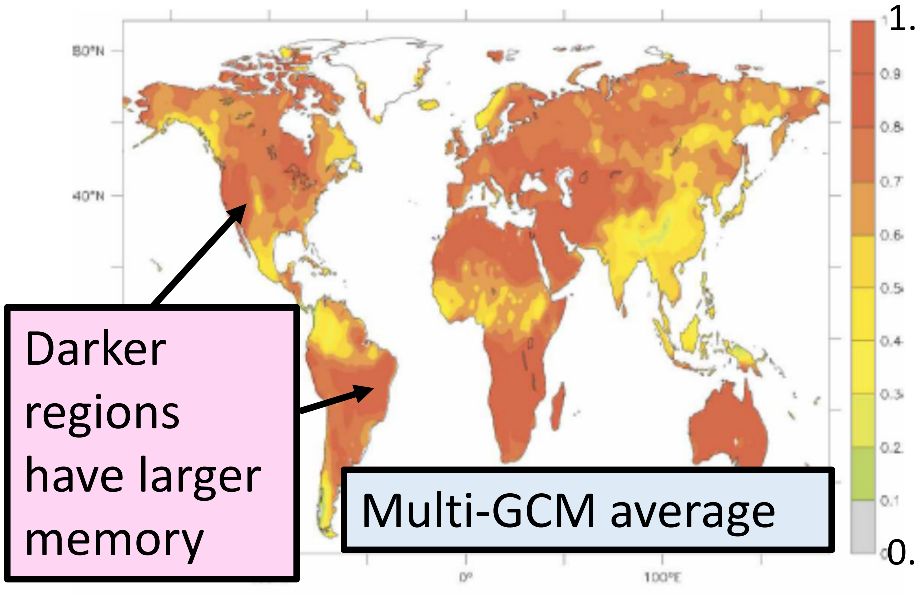
Goal of talk: To outline issues regarding land surface - atmosphere coupling as related to the subseasonal prediction problem.

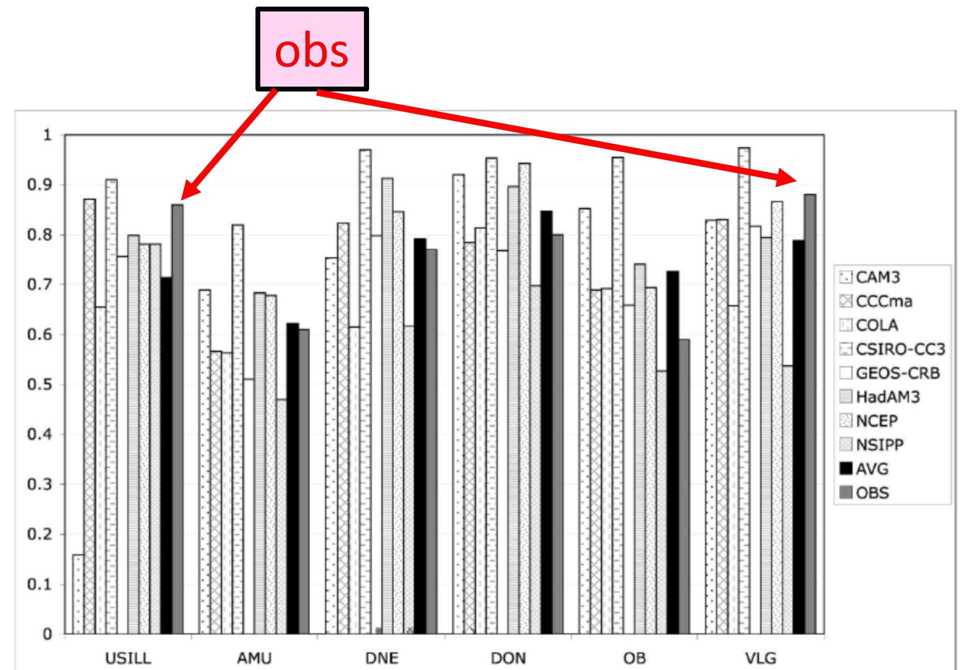
Strategy : List several relevant points germane to the topic -- some obvious, some perhaps less so…

1. Soil moisture has memory.

~1-month-lagged autocorrelations of soil moisture (boreal summer)

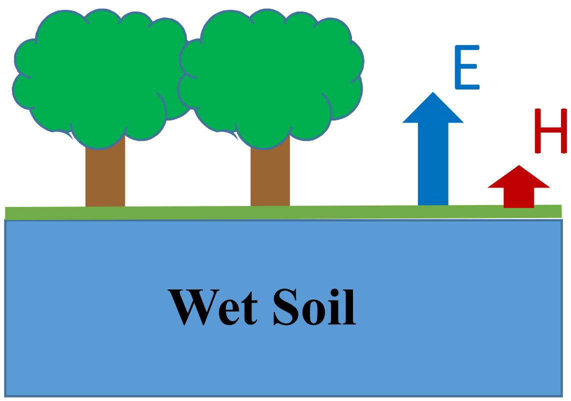


Model estimates roughly agree with observations, where the latter exist



Seneviratne et al., J. Hydromet., 7, 1090-1112, 2006

2. Through this memory, an initial soil moisture anomaly can influence the surface energy balance at subseasonal-to-seasonal timescales, perhaps influencing weather variables at these leads.



Wet soil ⇨ higher evap., lower sensible heat flux

This can affect local air temperature:

⇨ more evaporative cooling

⇨ lower air temperature

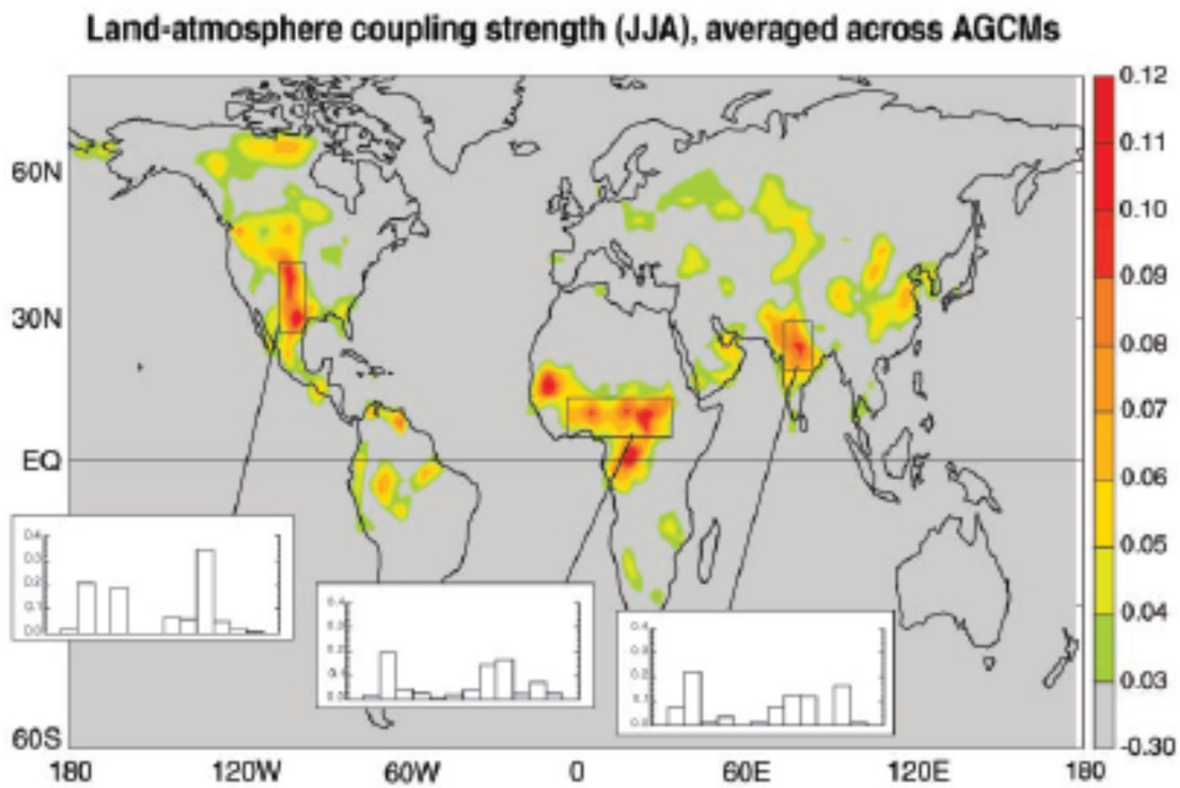
It can also affect local precipitation:

⇨ boundary layer modification

⇨ conditions more conducive (or perhaps less conducive) to onset of moist convection

3. The connection between soil moisture and the atmosphere seems to be strongest in transition zones between dry and wet areas.

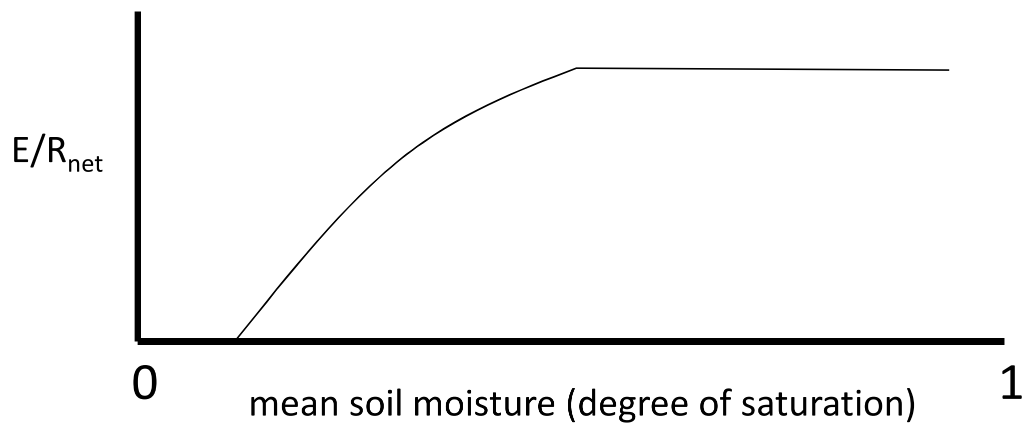
From the GLACE experiment: Multi-model estimate of where soil moisture variability affects (short-term) rainfall variability



Koster et al., Science, 305, 1138-1140, 2004

Why does land moisture have an effect where it does? For a large impact, need two things:

- a large enough evaporation signal
- a coherent evaporation signal – for a given soil moisture anomaly, the resulting evaporation anomaly must be predictable.



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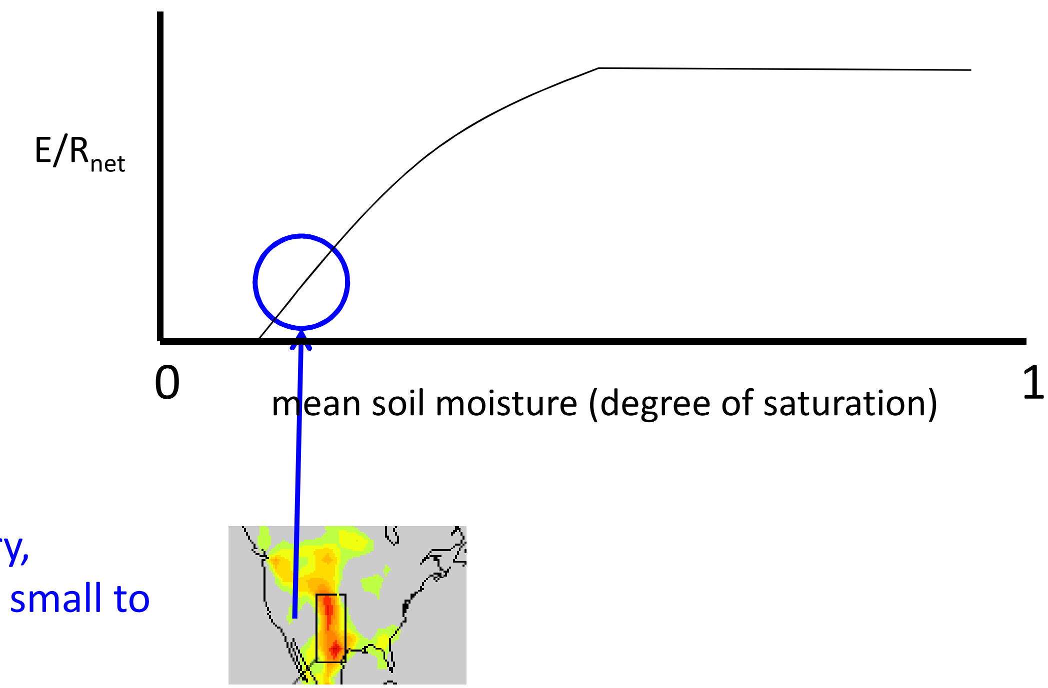

When it’s really dry, evaporation is too small to have an effect.

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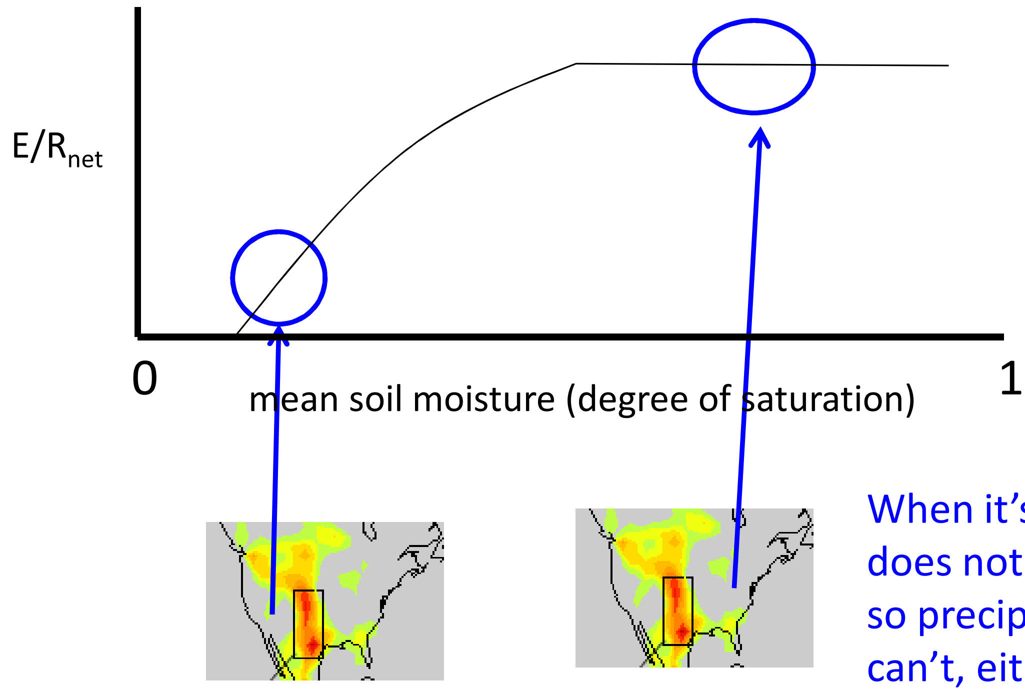
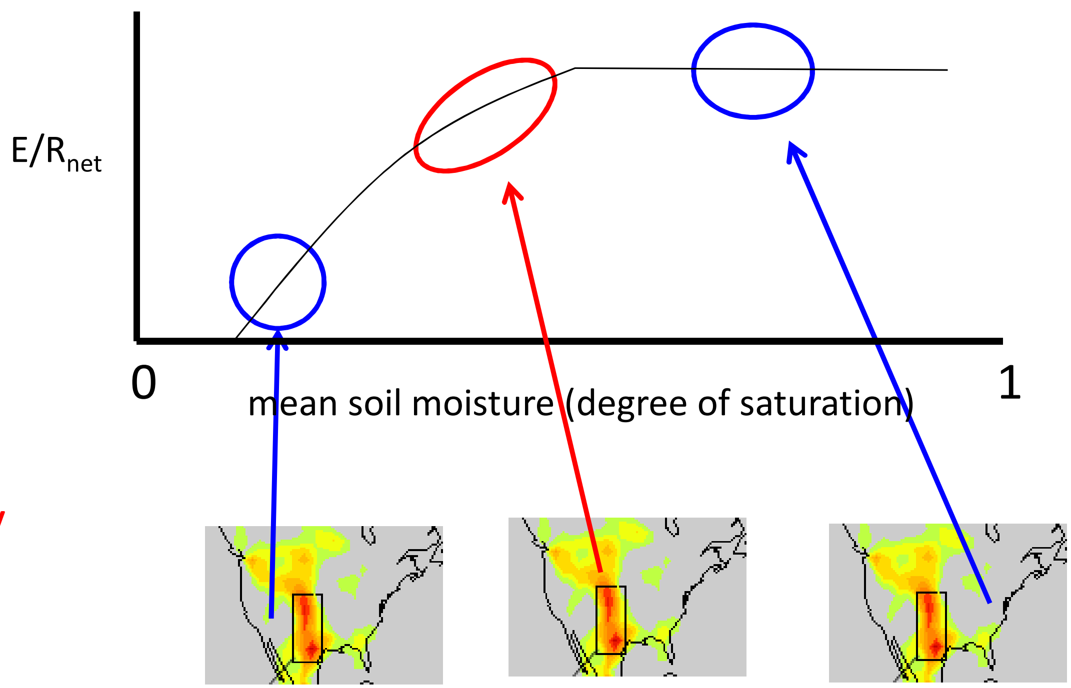


When it's really wet, evaporation does not vary with soil moisture, so precipitation and temperature can't, either.

Why does land moisture have an effect where it does? For a large impact, need two things:

- a large enough evaporation signal
- a coherent evaporation signal – for a given soil moisture anomaly, the resulting evaporation anomaly must be predictable.

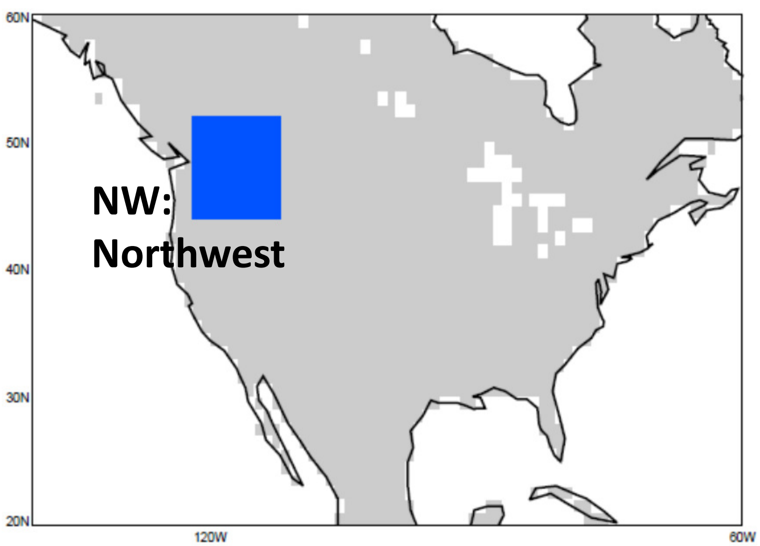
You mainly get an impact in the "sweet spot" in between: in the transition zone, where it's not too dry and not too wet.



4. Some intriguing land-atmosphere feedback mechanisms may allow *remote* soil moisture anomalies to affect local precipitation and temperature.

Control: An ensemble (192 members) of ~1°×1° simulations with the GEOS-5 AGCM. Period covered in each simulation: April – July 2012.

Experiment :



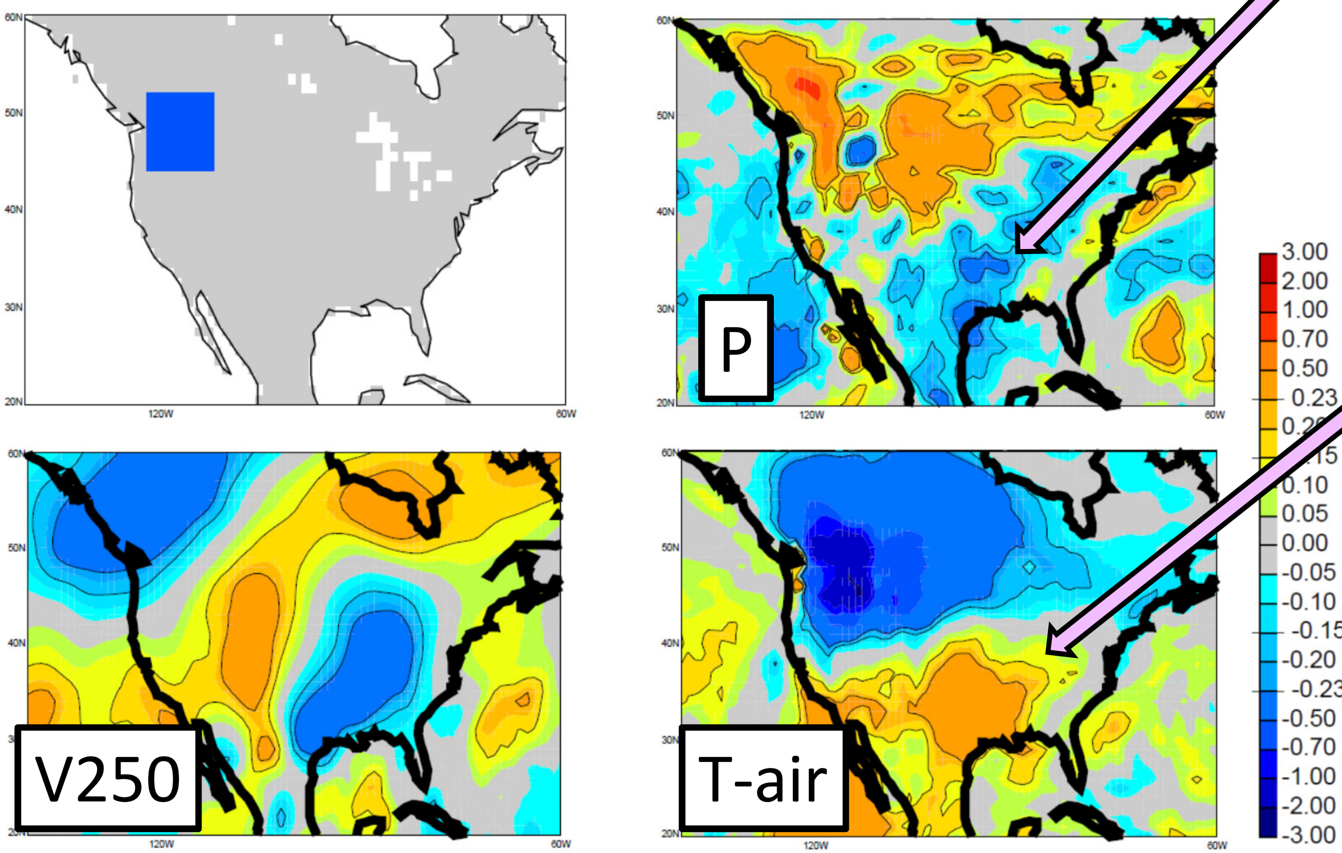
As control, except impose a very wet April in NW: multiply all April precipitation there by 5 and deposit as liquid.

Compare July results.

Results: V250, P, T-air

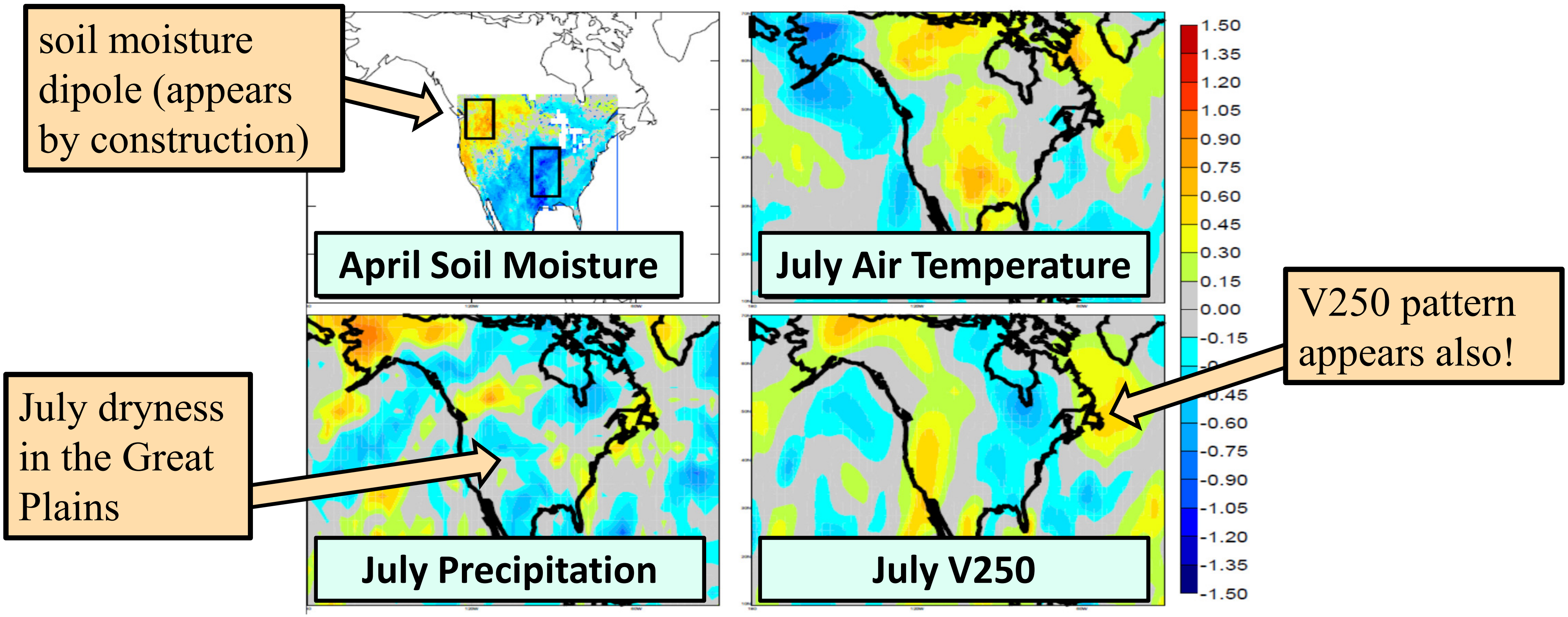
A remote impact on precipitation: a dry GP!

A remote impact on air temperature: a warm GP!



(All July V250, near-surface air temperature, and precipitation anomalies presented as standard normal deviates.)

Results: Observations



Koster et al., J. Climate, 27, 9290-9301, 2014

5. Soil moisture is known to contribute to forecast skill.

GLACE-2: **The 2nd phase of the Global Land-Atmosphere Coupling Experiment**
(an international, multi-institution project)

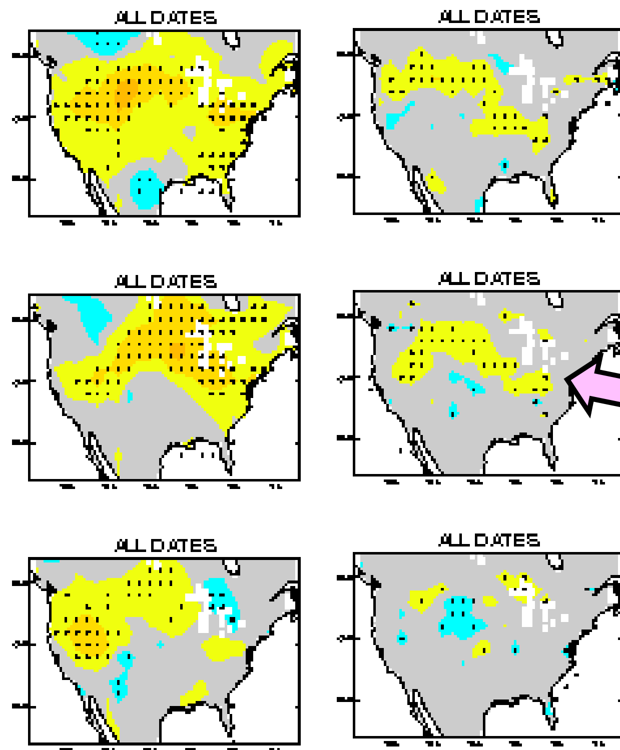
Gist of experiment:

Forecast skill from simulations with accurate land initialization	–	Forecast skill from simulations without accurate land initialization	=	Forecast skill due to land initialization

Koster et al., J. Hydromet., 12, 804-822, 2011

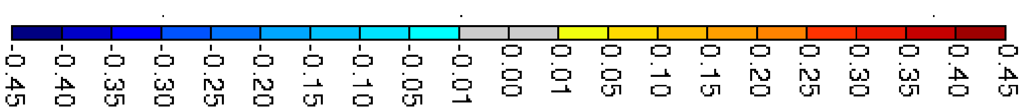
Forecasts: “Consensus” skill due to land initialization (JJA)

	temperature	precipitation
16-30 days		
31-45 days		
46-60 days		



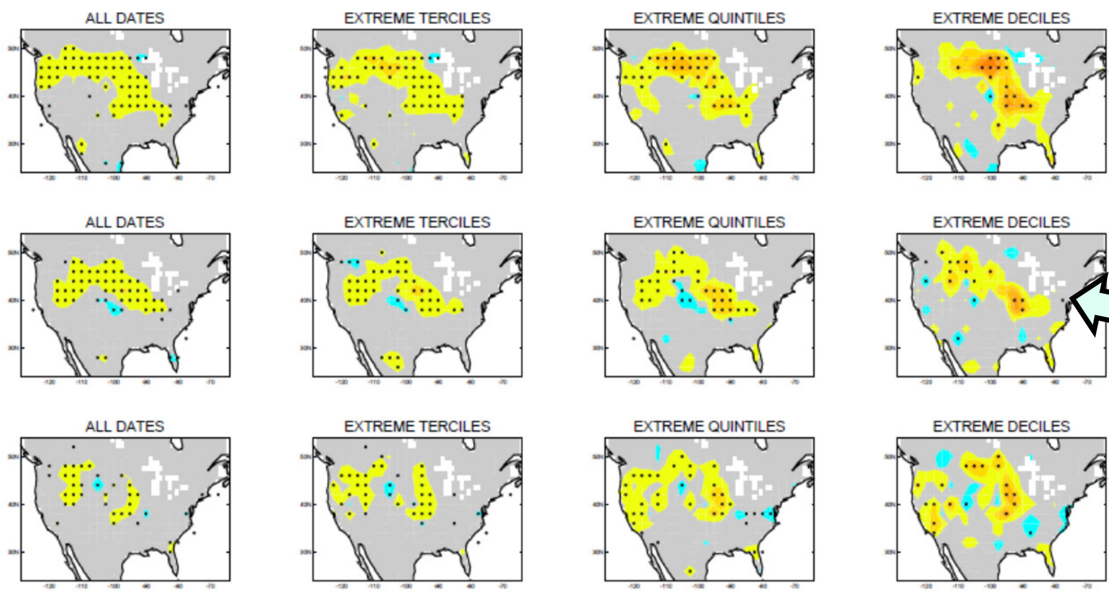
Some small contribution to precipitation forecast skill even beyond 1 month!

(“Weaker” models are averaged in with “stronger” ones.)



Precipitation forecasts: Increase in skill due to land initialization (JJA)
(conditioned on strength of local initial soil moisture anomaly)

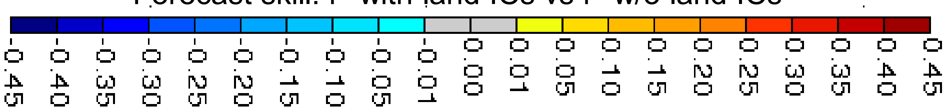
	all points	Extreme terciles	Extreme quintiles	Extreme deciles
16-30 days				
31-45 days				
46-60 days				



Dates for conditioning vary w/location

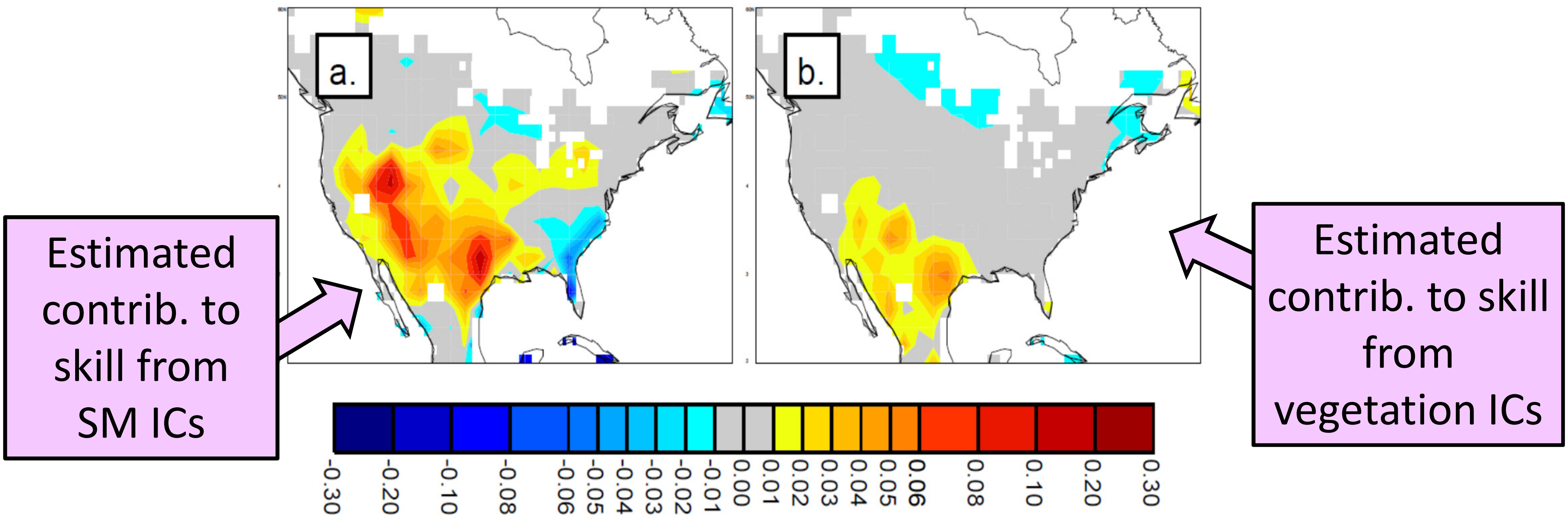
Contributions to forecast skill increase when only larger initial soil moisture anomalies are considered.

Forecast skill: r^2 with land ICs vs r^2 w/o land ICs



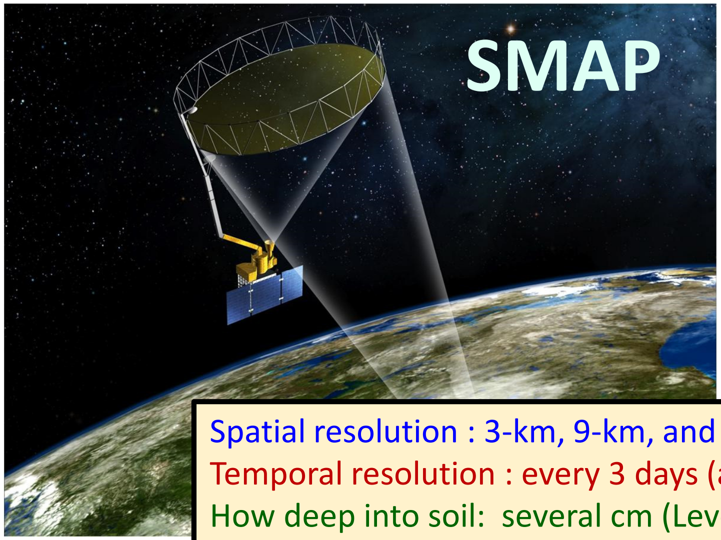
6. Vegetation phenology also has a memory that may (eventually) contribute to forecast skill.

Perform GLACE2-like experiment with dynamic phenology model



Koster et al., J. Hydromet., in press

7. New satellite-based L-band sensors have the potential to provide valuable global soil moisture data for use in subseasonal prediction.



Spatial resolution : 3-km, 9-km, and 36-km
Temporal resolution : every 3 days (at least)
How deep into soil: several cm (Level 1-3)
1 m (Level 4)
Accuracy: RMSE < 4 volumetric percent
Latency: short! (hours – days)
Baseline mission duration: 3 years

Summary of Points Made

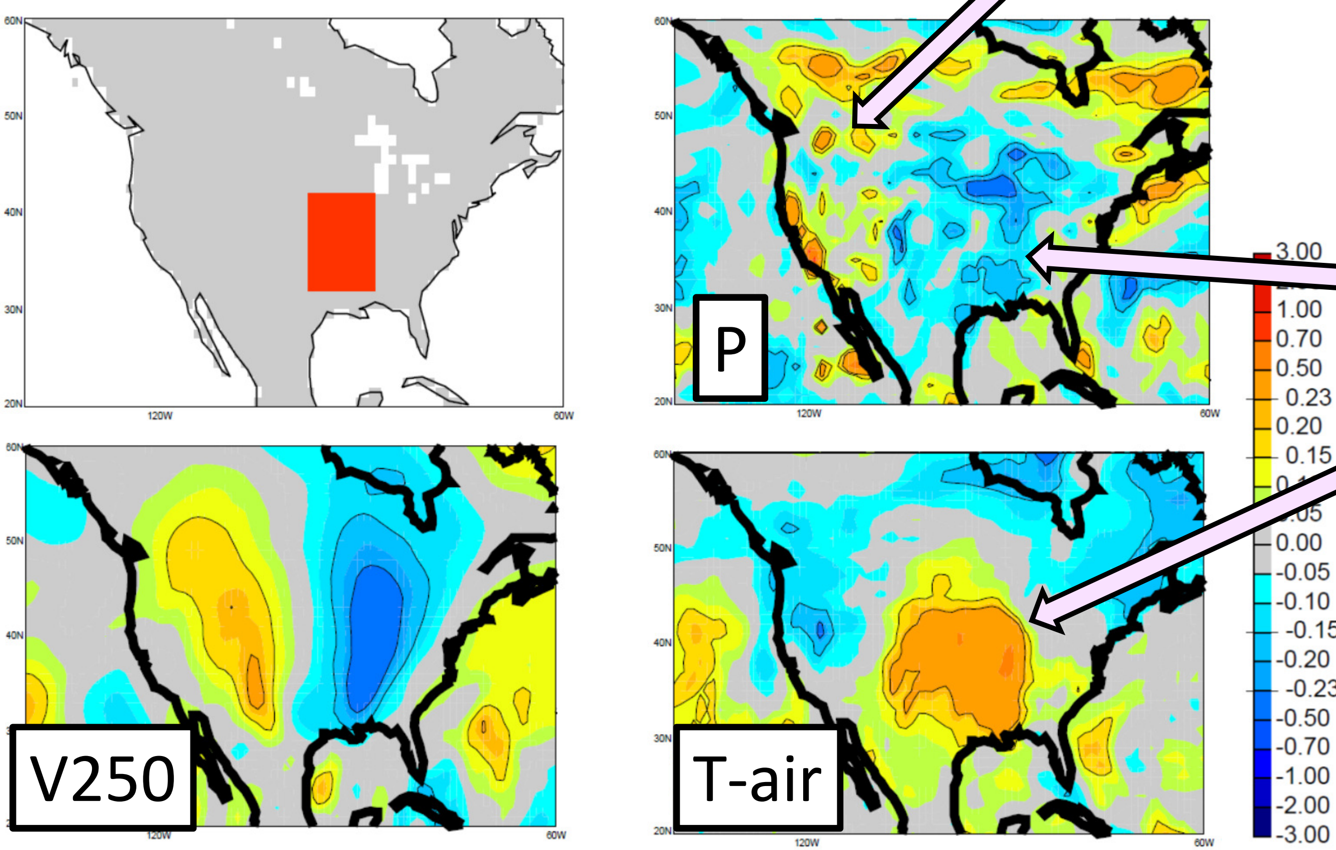
1. Soil moisture has memory.
2. Through this memory, an initial soil moisture anomaly can perhaps influence weather variables at subseasonal to seasonal leads.
3. The connection between soil moisture and the atmosphere seems to be strongest in transition zones between dry and wet areas.
4. Certain land-atmosphere feedback mechanisms allow *remote* soil moisture anomalies to affect local precipitation and temperature.
5. Soil moisture is known to contribute to forecast skill.
6. Vegetation phenology's memory can contribute to forecast skill.
7. New satellite-based sensors should provide new and valuable data.

Demonstration of actual (if sometimes small) forecast skill improvements from experiments involving accurate land initialization

(extra slides)

Results: V250, P, T-air

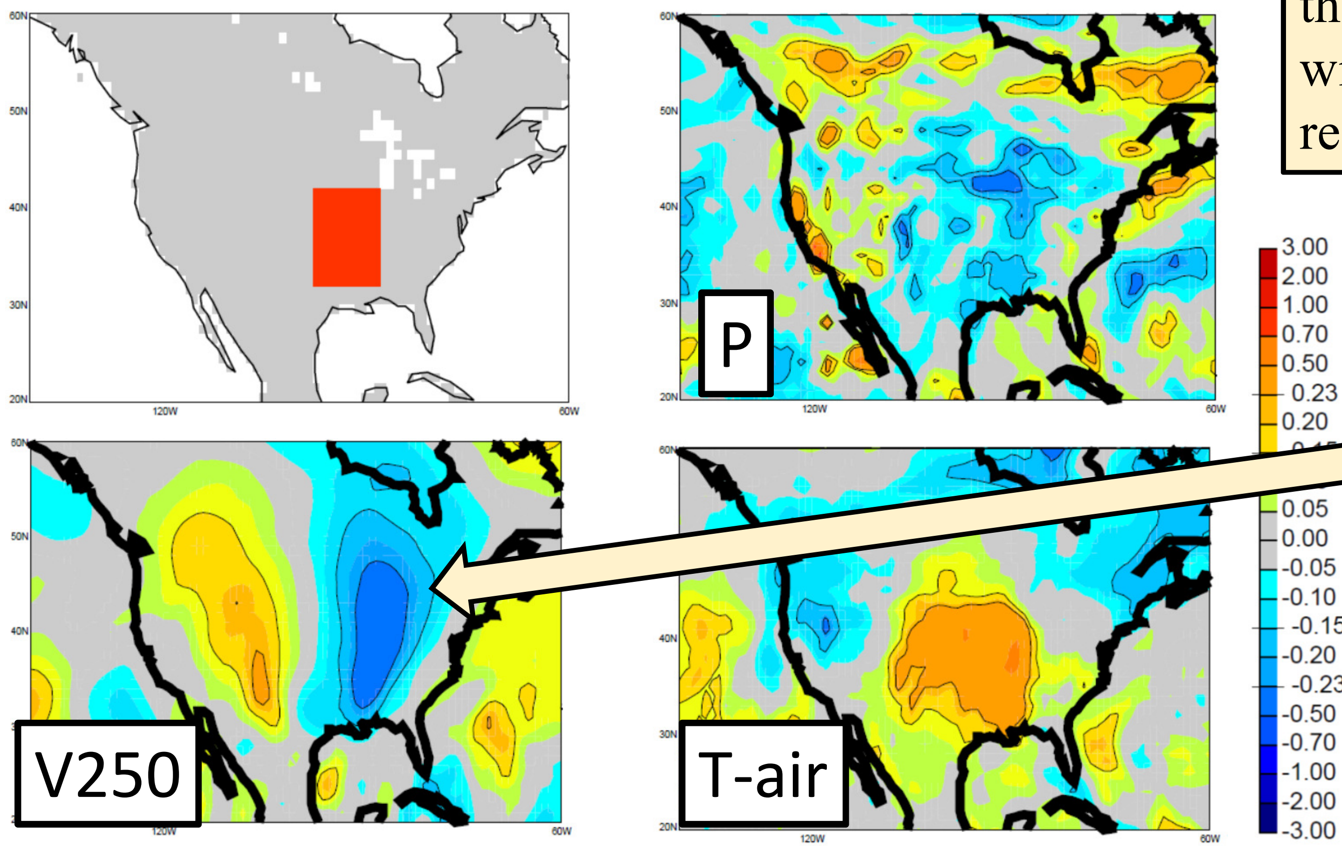
No upstream remote effect to speak of…



… but a large impact in the Great Plains. This is intriguing in its own way (next slide).

Results: V250, P, T-air

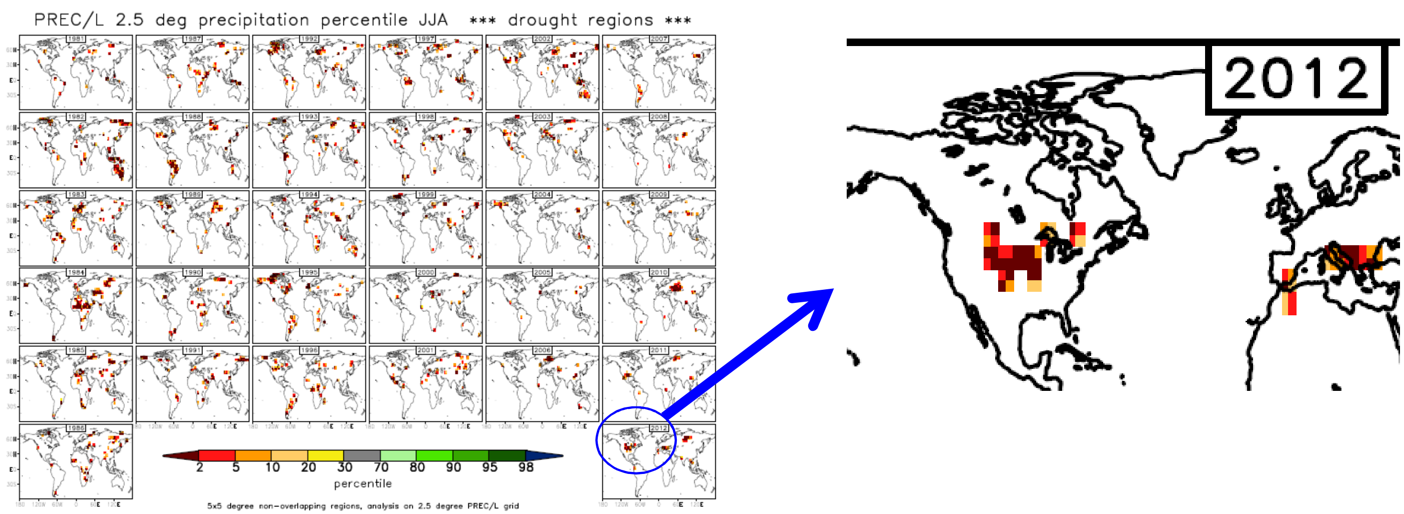
Presumably the main cause of warming in and drying in the GP is local feedback, with dry soil leading to reduced evaporation.



A secondary, but still important, cause of warming and drying in GP is the enhancement of the existing signal by the phase-locking of the stationary wave.

Global evaluation of drought forecasts over the period 1981-2012 with the GMAO forecast system

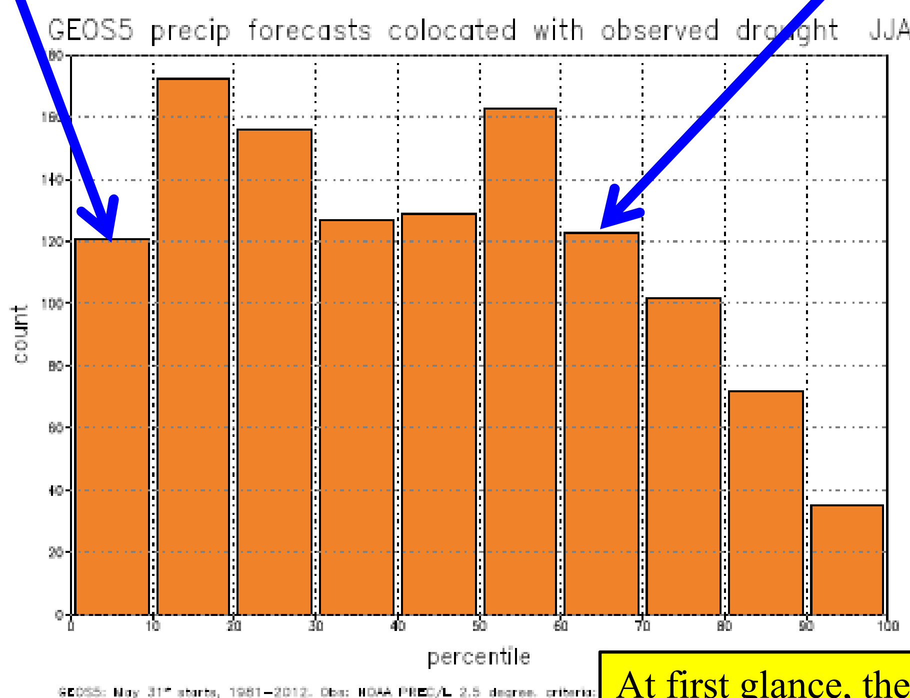
Step 1: Locate times and locations for which the observations show JJA precipitation (across a 5°x5° area) to be in the lowest (driest) decile.



Step 2: Determine whether the corresponding GCM forecasts (initialized in early June) also place the JJA precipitation in the lowest decile.

If, in a given instance, the forecast system accurately predicted JJA precipitation to be in the lowest decile, add a count to this bin.

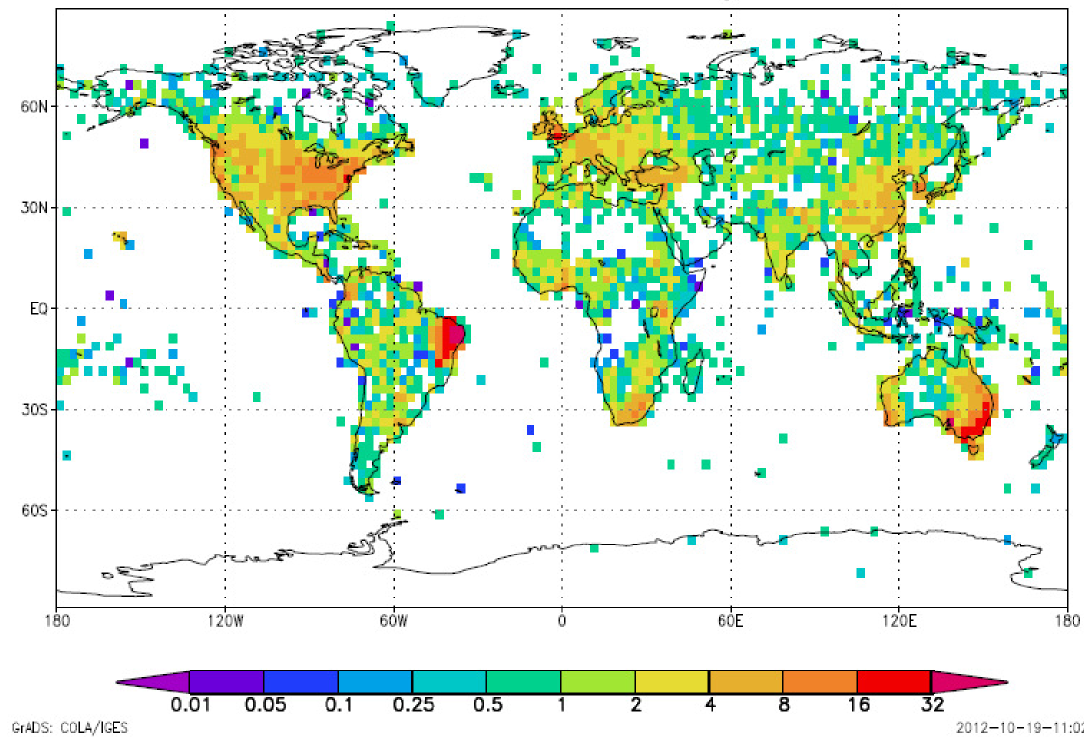
If the forecast system predicted precipitation to be in the 60%-70% decile, add a count to this bin.



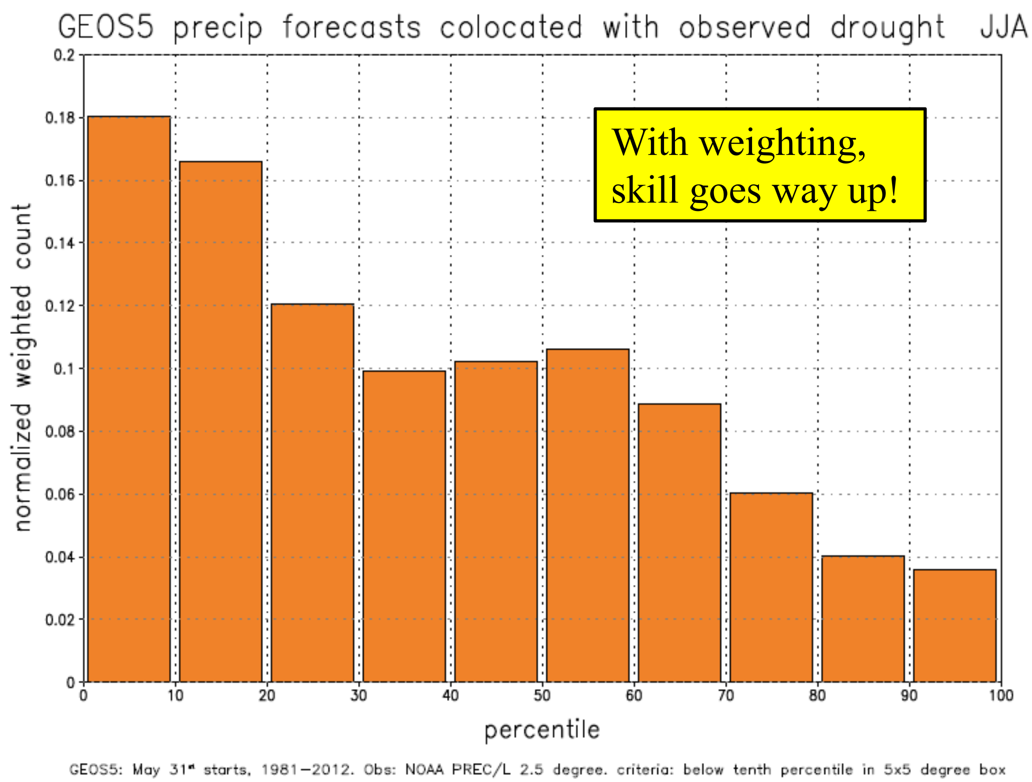
At first glance, the forecast system appears to have little skill.

Note, however, that in the binning procedure, we are giving equal weight to all predictions, including those in locations for which we have very little information about the precipitation.

Number of rain gauges per 2.5°x2.5° cell JJA avg 1981–2012

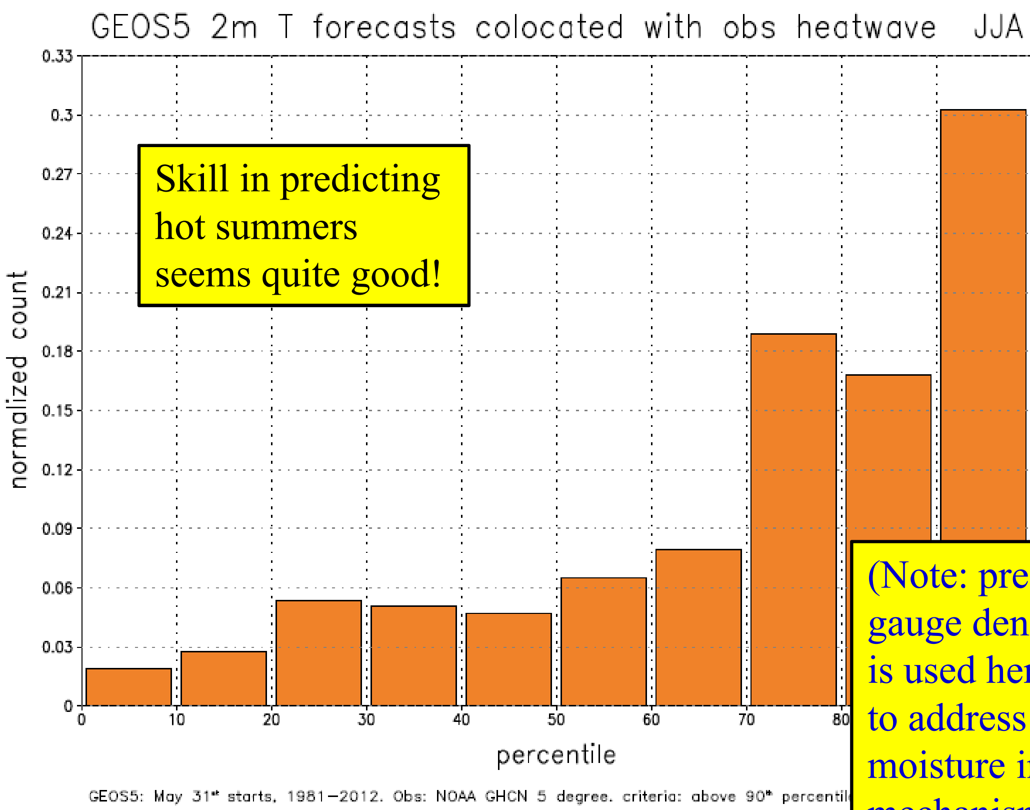


We can weight the counts added to a given bin by the density of rain gauges within the area considered ➡ perhaps a more sensible approach to evaluating forecast skill.



Now perform a similar exercise for air temperature (T2M):

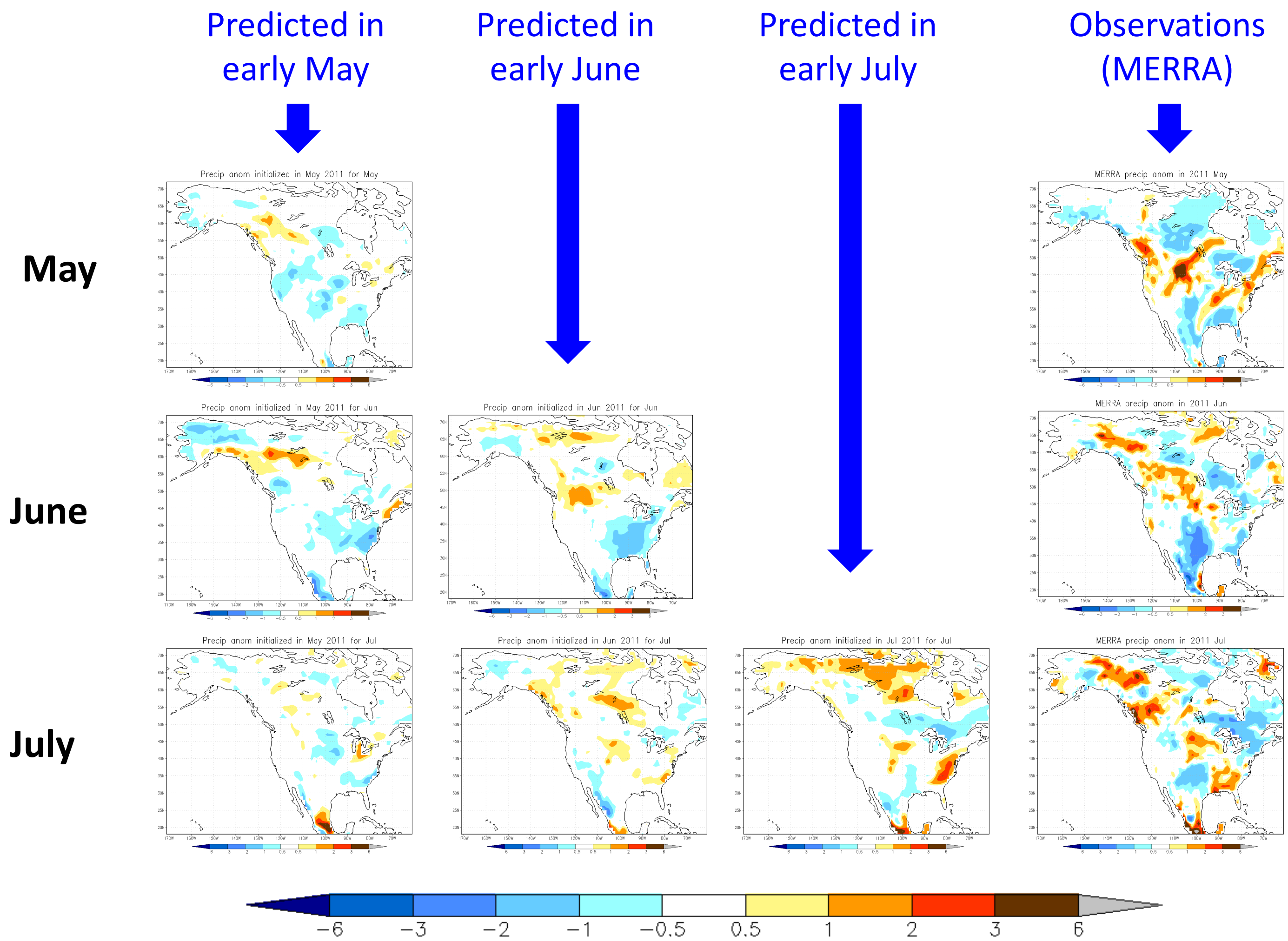
1) Determine the instances for which the observations show JJA temperatures (at $5^o x 5^o$) to be in the warmest decile.
2) Bin the forecasted JJA T2M percentiles for these instances accordingly.



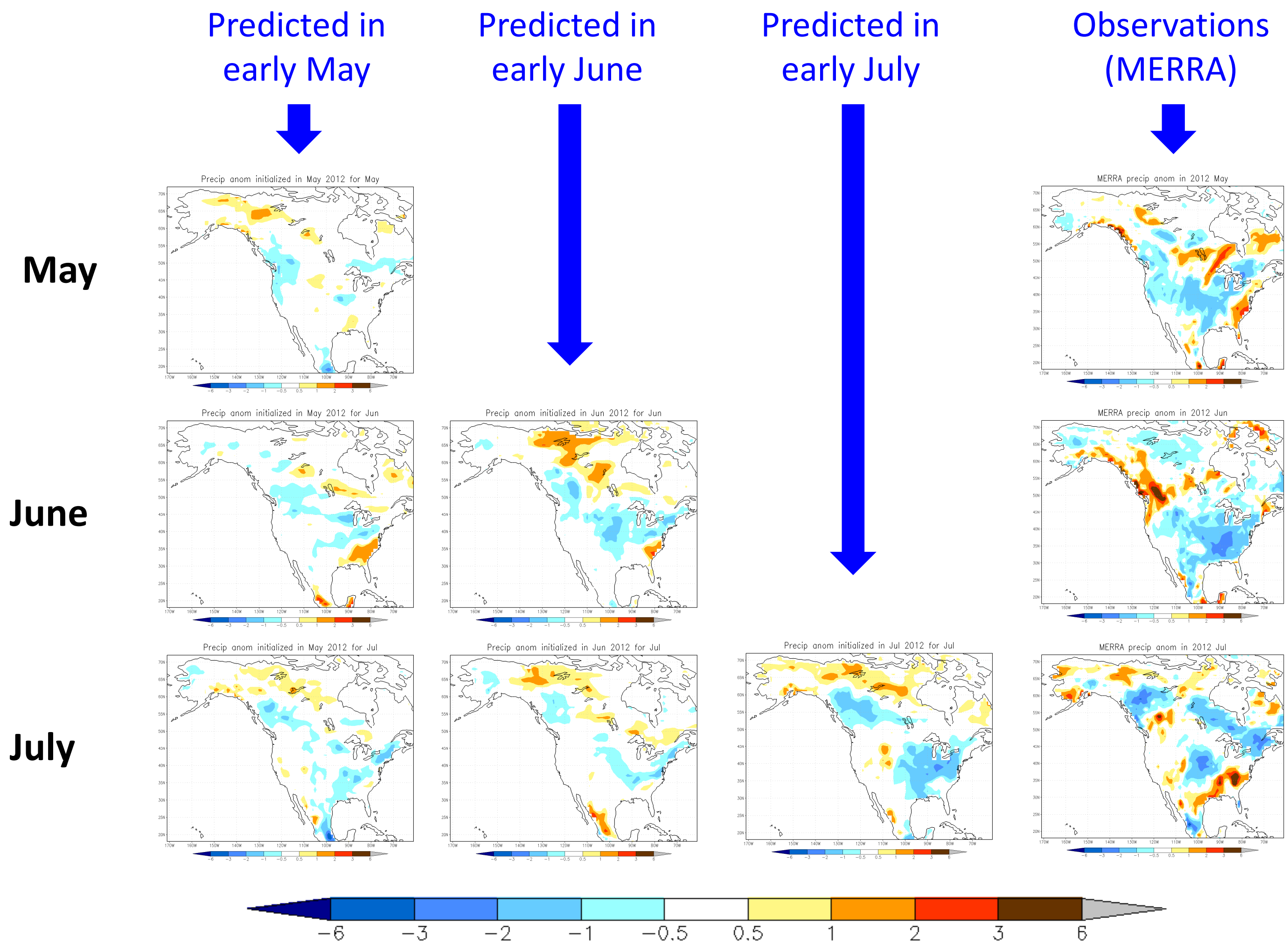
Skill in predicting hot summers seems quite good!

(Note: precipitation gauge density weighting is used here also in order to address the soil moisture initialization mechanism.)

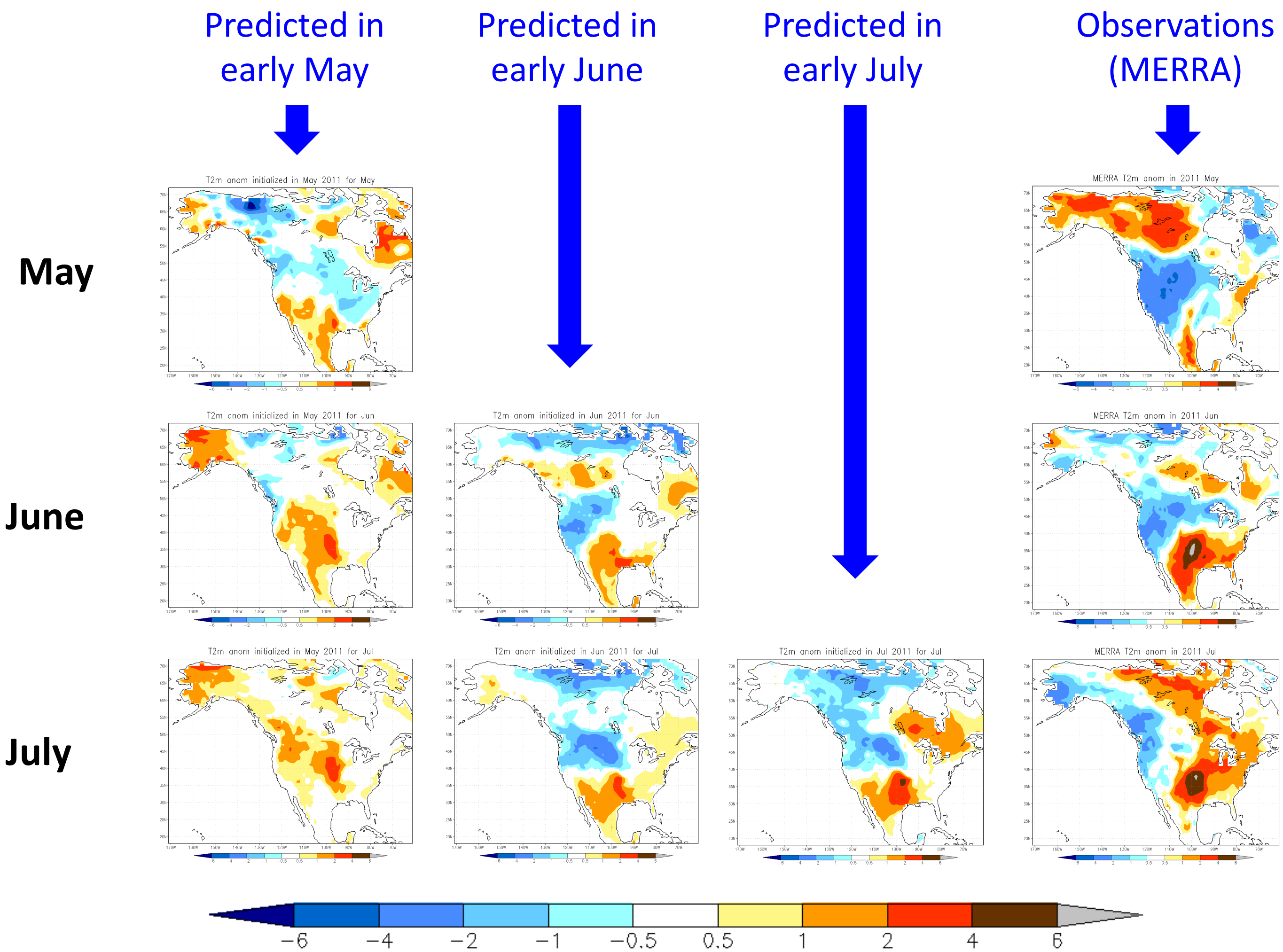
Precipitation Anomaly Forecasts: Summer 2011



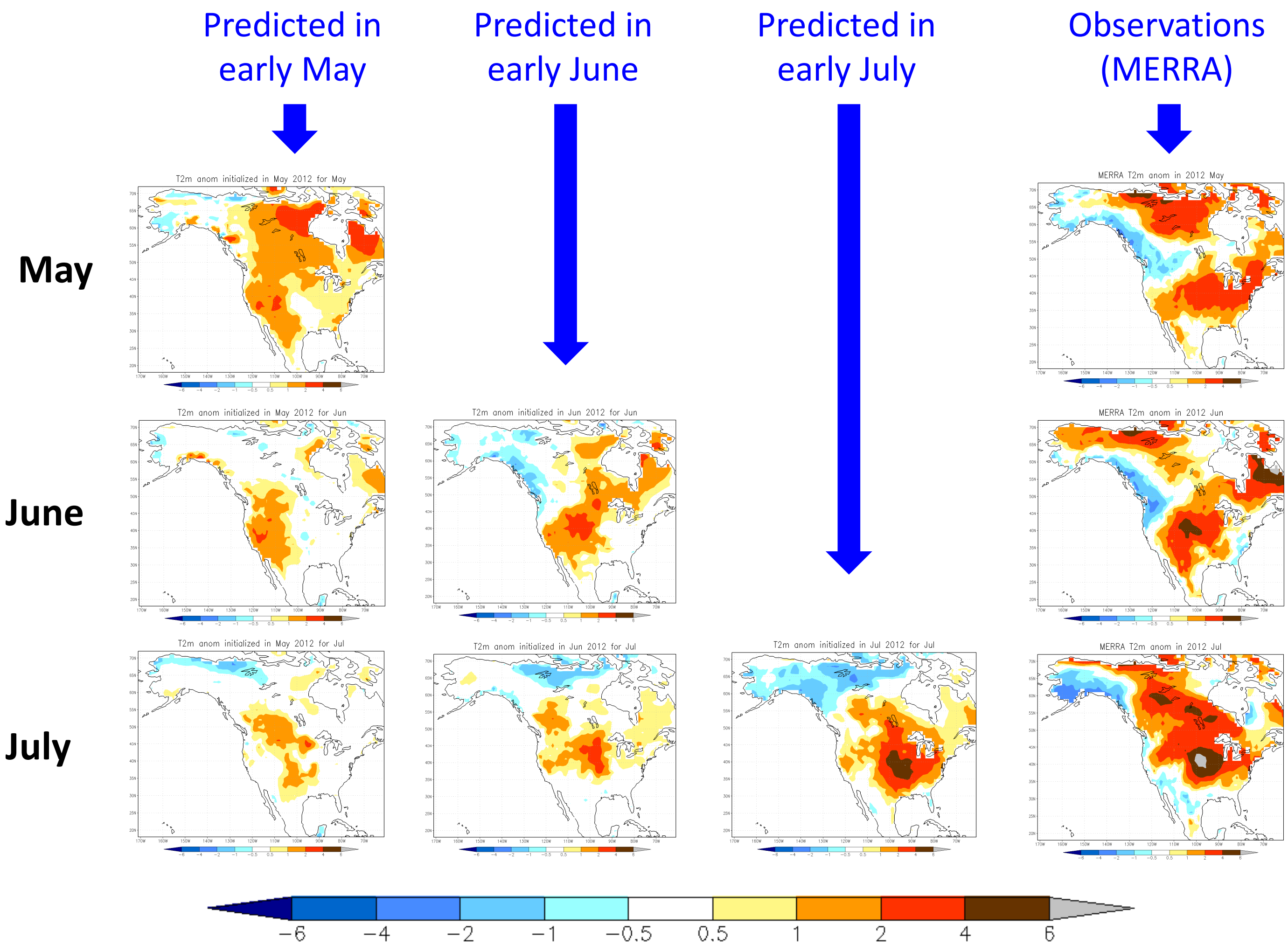
Precipitation Anomaly Forecasts: Summer 2012



Temperature Anomaly Forecasts: Summer 2011



Temperature Anomaly Forecasts: Summer 2012

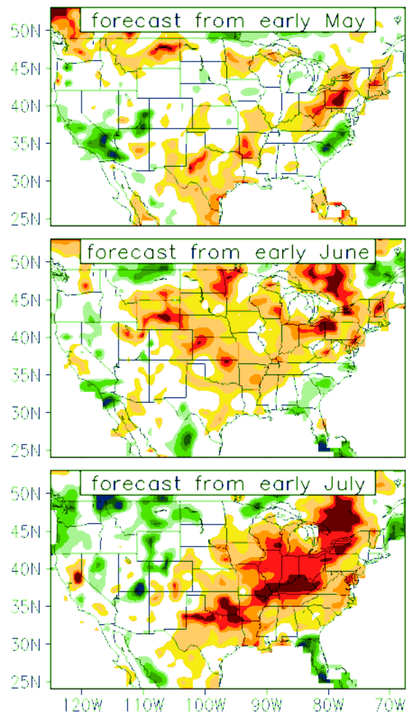


Soil Moisture Percentile Forecasts: July 30, 2012

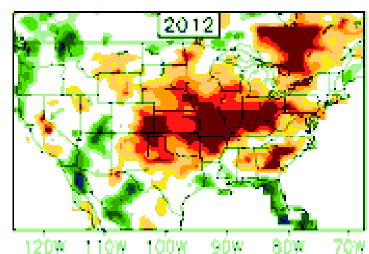
Predicted in early May

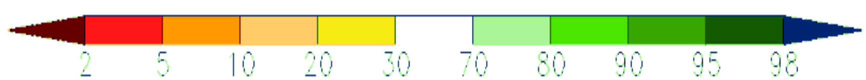
Predicted in early June

Predicted in early July



Estimated "truth"

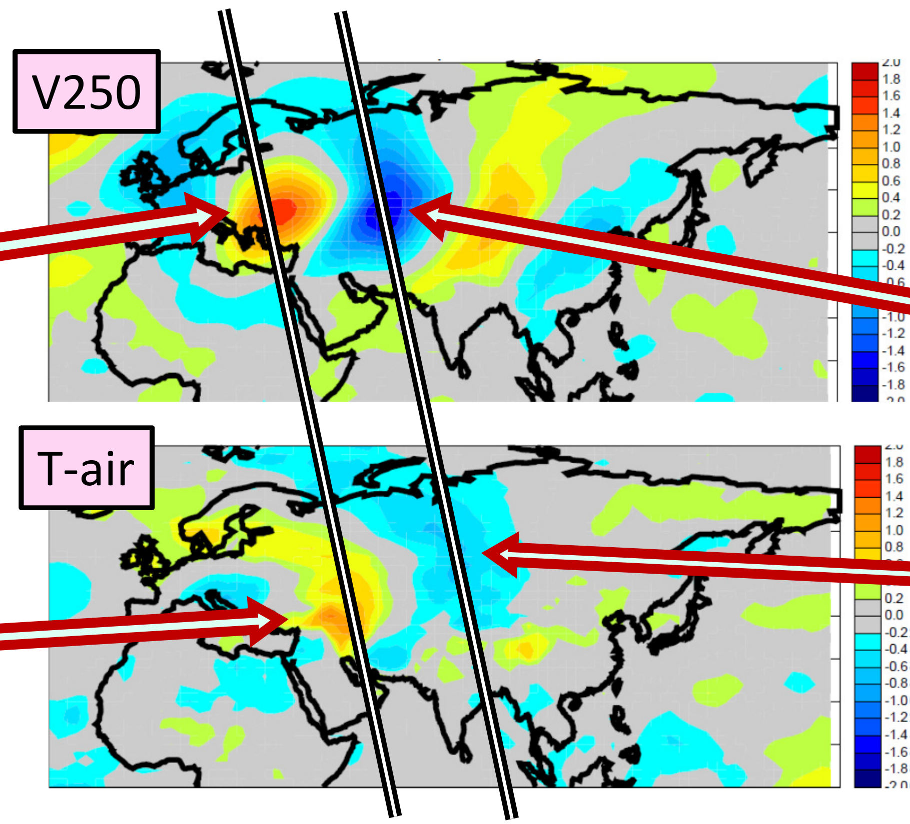




Interesting fact: near-surface air temperature (T-air) and precipitation (P) anomalies tend to be correlated with V250 anomalies.

Northward flow here…

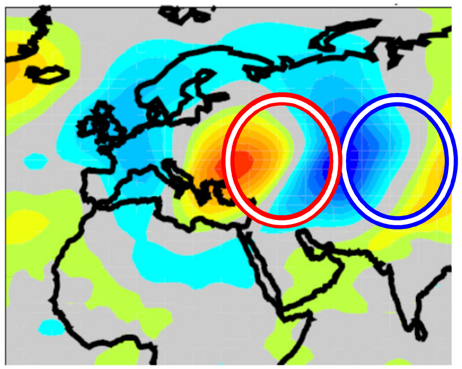
Southward flow here…



…tends to induce warm surface temperatures here (along with lower rainfall)

…tends to induce cool surface temperatures here (along with higher rainfall)

Why? Two possible reasons:



1) Northward winds bring in warm air from the south. The vertical structure of wind field is slanted, so that the maximum of the northward and southward winds at the surface are displaced (relative to the V250 winds) toward the east.

2) The V250 field is associated with a 250 mb height field that, for northward flow, encourages subsidence: less rain, warmer temperatures.

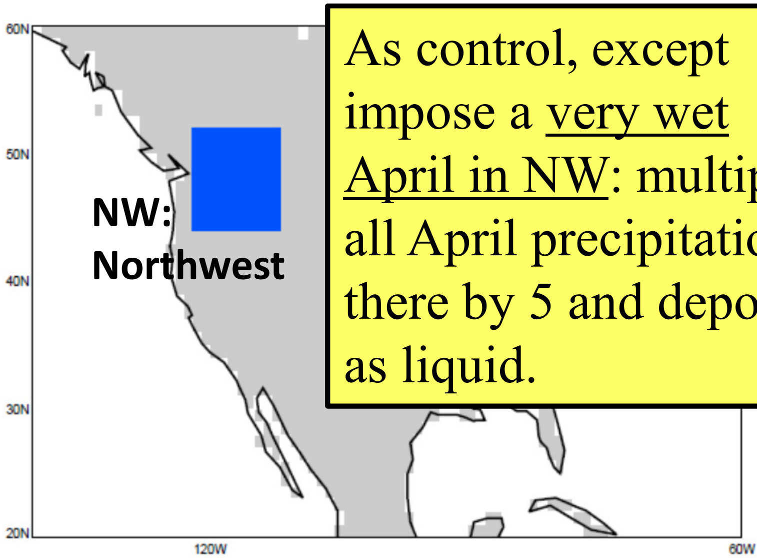
These mechanisms are not explored further here; suffice it to say that **V250 anomalies are able to induce corresponding anomalies (slightly to the east) in surface temperature and rainfall.**

Step 2: Design specialized experiments

Control: An ensemble (192 members) of ~1°×1° simulations with the GEOS-5 AGCM. Period covered in each simulation: April – July 2012.

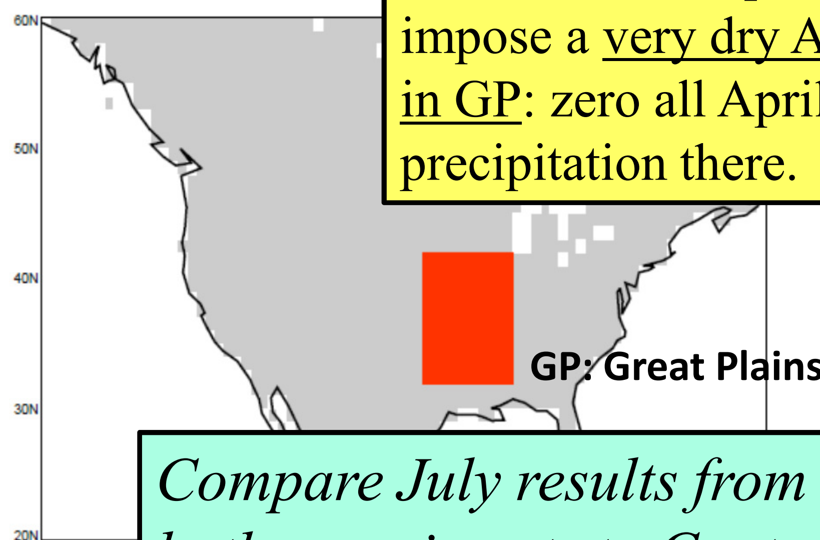
Experiment 1:

As control, except impose a very wet April in NW: multiply all April precipitation there by 5 and deposit as liquid.



Experiment 2:

As control, except impose a very dry April in GP: zero all April precipitation there.



Compare July results from both experiments to Control.

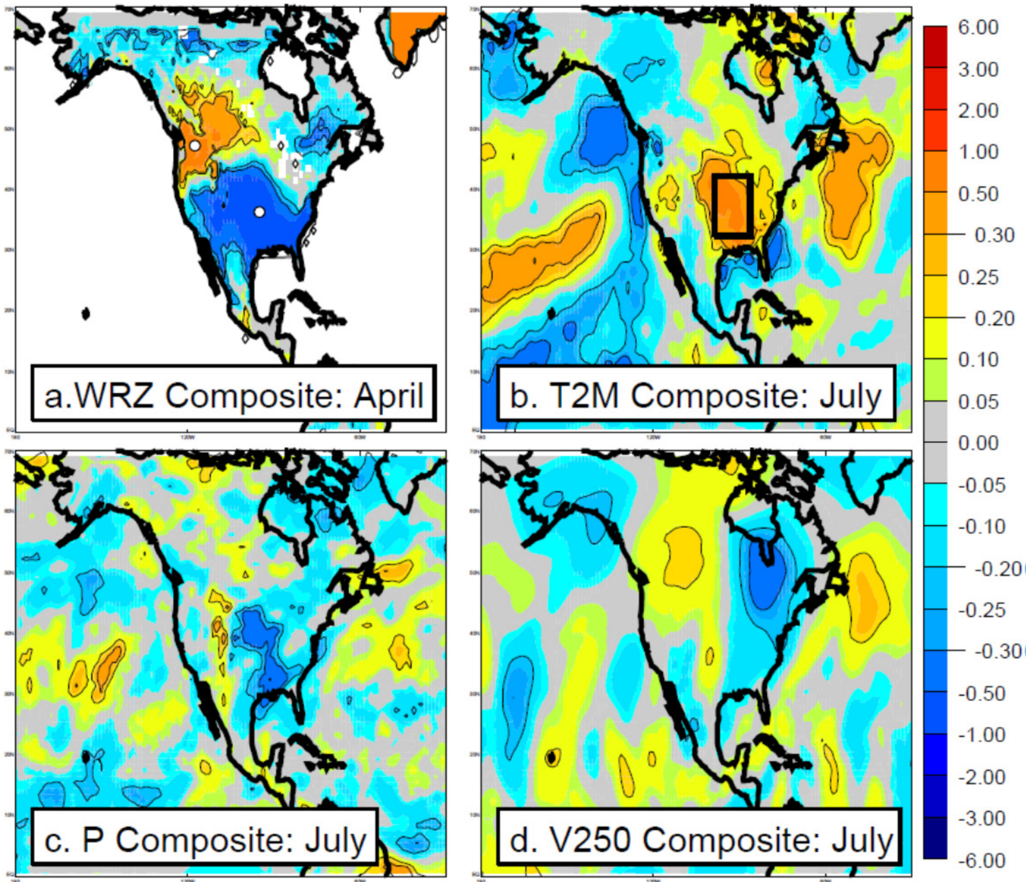
Data considered (1979-2013)

Soil moistures: VIC product from NLDAS project (Xie et al. 2012)

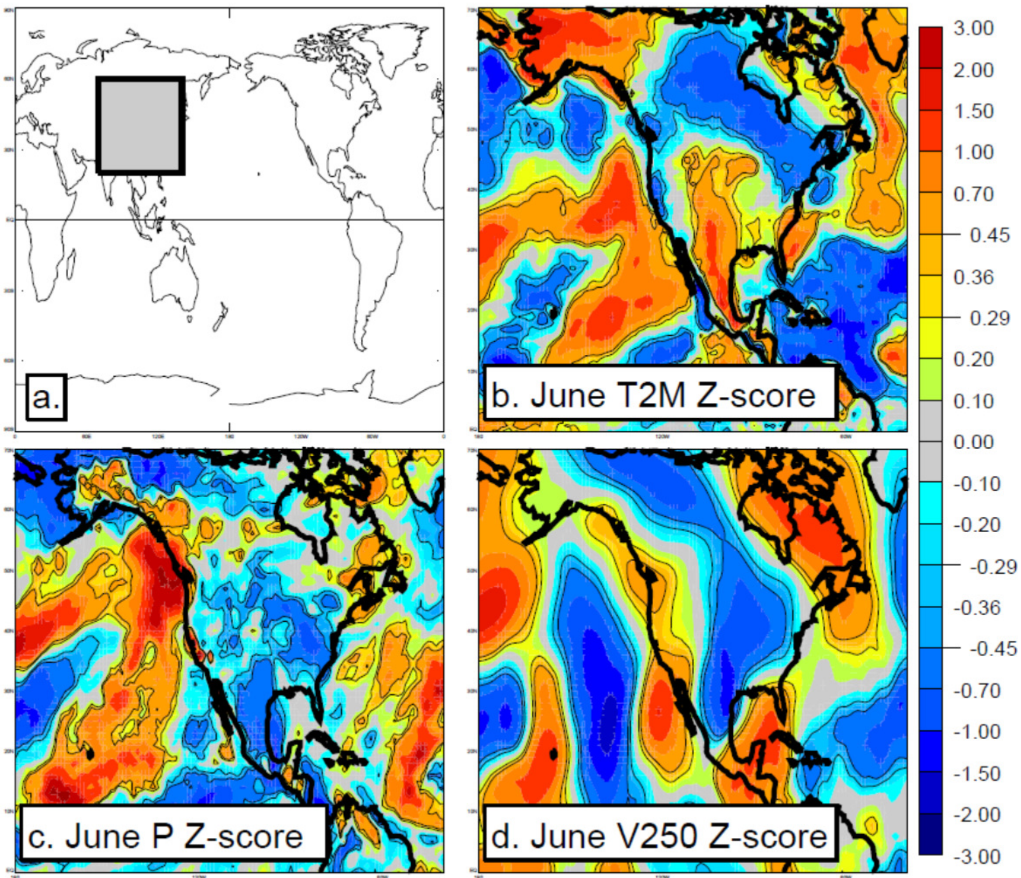
Temperatures: ERA-Interim 2-meter temperatures (Dee et al. 2011)

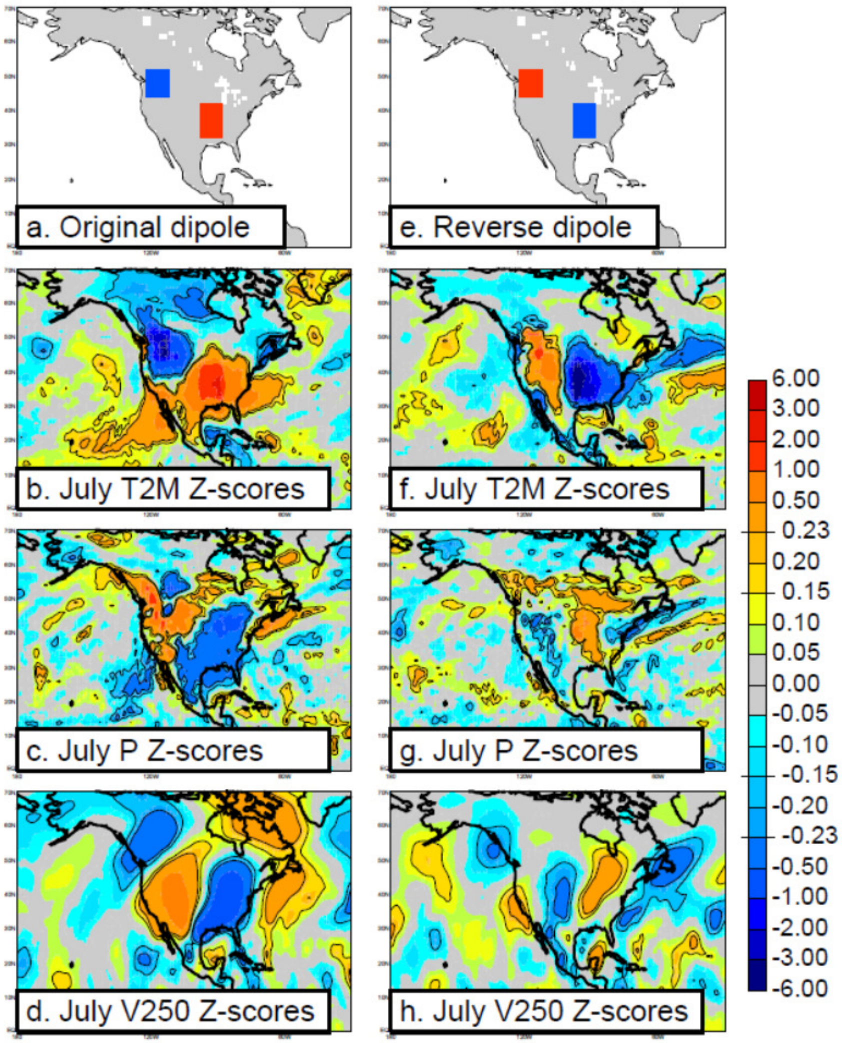
Meridional winds at 250 mb: ERA-Interim V250 fields (Dee et al. 2011)

The VIC data point to 9 years with a soil moisture dipole in April. We composite the standardized anomalies over these 9 years.



a.WRZ Composite: April
b. T2M Composite: July
c. P Composite: July
d. V250 Composite: July
6.00
3.00
2.00
1.00
0.50
0.30
0.25
0.20
0.10
0.05
0.00
-0.05
-0.10
-0.20
-0.25
-0.30
-0.50
-1.00
-2.00
-3.00
-6.00


a.
b. June T2M Z-score
c. June P Z-score
d. June V250 Z-score
3.00
2.00
1.50
1.00
0.70
0.45
0.36
0.29
0.20
0.10
0.00
-0.10
-0.20
-0.29
-0.36
-0.45
-0.70
-1.00
-1.50
-2.00
-3.00



Dipoles here are imposed during all of April-July, not just in April.